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NAVAL OCEAN RESEARCH AND DEVELOPMENT ACTIVITY NSTL
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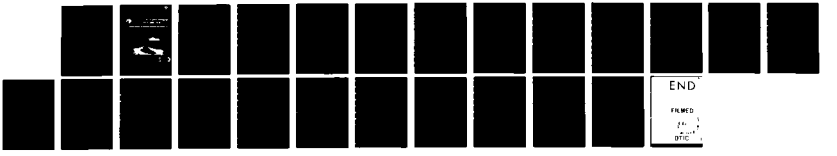
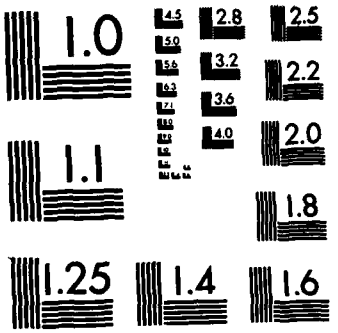


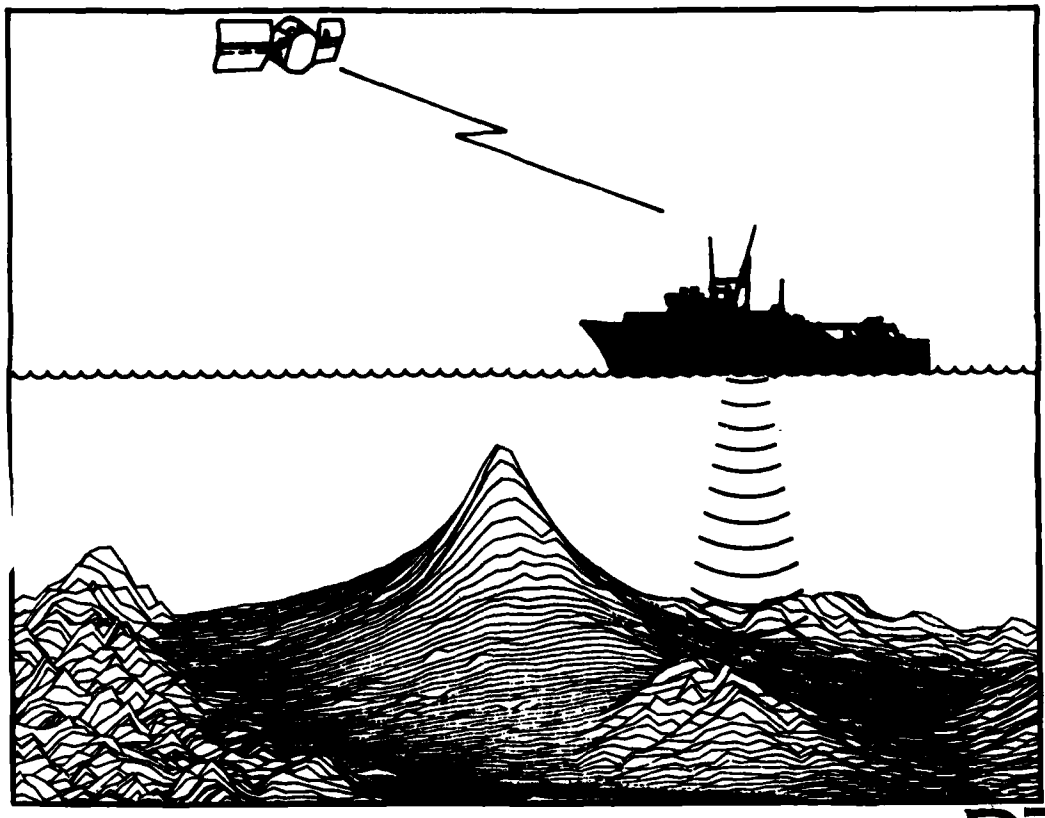


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

NORDA Technical Note 201

Naval Ocean Research and
Development Activity
NSTL Station, Mississippi 39529

A Plan for Optical Oceanography R&D to Support MC&G



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ABSTRACT

This study was undertaken to determine a course of action for NORDA to provide a balanced R&D program in optical oceanography to support MC&G requirements. Aspects considered in this analysis include an initially broad view of general MC&G requirements for ocean optics, a review of existing programs, sponsors and funding in ocean optics, and an assessment of available NORDA resources in ocean optics. Current technical literature in ocean optics and optical instrumentation was also reviewed to establish the current state of knowledge and technology. An integrated coastal ocean optics program covering basic research, exploratory development, and advanced development, using all relevant available NORDA resources is recommended. This work was funded by Dr. J. Andrews, NORDA Technical Director, under Program Element 65861N.

SUMMARY AND CONCLUSIONS

The Defense Mapping Agency has established a requirement for the Navy to do basic and applied research to support the development of optical remote sensors used for hydrographic charting. Many current optical oceanography programs support MC&G objectives to a certain extent. For instance, ONR efforts to measure and understand diffuse attenuation are supportive of airborne laser sounder technology. But the experimentation being performed, such as the ODEX, is usually done in clear, deep ocean waters, not in the shallow coastal areas with the more turbid waters. The scientific objective--to better understand how light propagates through natural waters--is the same, but the water is different. Deep ocean waters have beam attenuation coefficients of about 0.06; coastal waters may be more typically over 0.2. No project or program at the 6.1 or 6.2 level is addressing broad questions in coastal ocean optics.

Some of the current R&D is so closely allied to MC&G that any work done for MC&G will also support those programs. For example, the technology for SLC is closely related to airborne laser sounding technology. Both are highly concerned with increasing the penetration depth and detection of a pulsed laser beam. Proposed MC&G programs could possibly get some funding support from other programs if the application could be clearly shown.

Most of the basic research is to develop new equipment and make measurements under controlled conditions in the laboratory or in the field. The exploratory development projects also concentrate on equipment development and observation. Some of the work being done is classified.

The ONR and NORDA programs in bioluminescence R&D may provide data on background noise that can be applied to the HALS development program.

The ocean optical propagation models which define temporal distortions have been developed to the point where, to understand them better, they need to be tested against real data. Testing will require an accurate laser sounder and ground truth equipment capable of providing the spectral volume scattering function (VSF) and the spectral absorption of the ambient waters. Direct measurement of the VSF is difficult. Therefore, some indirect but accurate means of obtaining this value will have to be found to collect data from a large number of coastal areas at a reasonable cost.

CONTENTS

A PLAN FOR OPTICAL OCEANOGRAPHY R&D

TO SUPPORT MC&G

I. INTRODUCTION

The technical issues concerning a coastal ocean optics program are centered on how light propagates through natural waters. Adequate theoretical models on light propagation in natural waters are not available for the increasingly accurate optical remote systems being developed. Excellent measurements and tests of particular optical qualities have been made in natural waters. In addition to Duntley's (1963) "Light in the Sea," T. J. Petzold's and L. E. Merten's measurements of volume scattering spring to mind; but the trouble with most of these data is that they apply to only a particular body of natural water in which the measurements were made. Since the information was not gathered with remote sensors in mind, many things such as specific color or particle size distribution were not always measured, and it cannot be assumed that the results would hold for a different natural water. Another difficulty is that most of the work has been done in very clear waters, not typical of the coastal waters of high interest to the Navy and DMA. A propagation model for coastal waters is needed. This model should include frequency (color), density (filter effect of colored solutions, gels, or mixtures), particles (size distributions, amounts, and biology), temperature, salinity, field of view, and perhaps other factors. The model should be good enough to make accurate determinations, with a few assumptions as to homogeneity of, for example, depth and bottom reflectivity from remote sensors.

The traditional and most used optical parameter of ocean waters is diffuse attenuation. It is measured simply by lowering an upward-looking photometer down to measured depths. While this information is the most useful to ocean biology, it is not an inherent optical quality. The same water can have different values for different sun angles, cloud cover, wave heights, and winds. Inherent optical qualities, such as beam attenuation or absorption, always are constant for the same water regardless of the sun angle, cloud cover, etc. These inherent qualities may prove to be of more value to the development of the optical remote sensors used for MC&G.

The key to understanding how light propagates in natural waters is scattering. Speed (index of refraction) is well known as a function of temperature and salinity, at least for some colors. Attenuation, both beam and diffuse, is less well known but can be measured. Particle size distribution measurements and the chemical analysis of particles and colored solutions can be done with considerable accuracy. Measurements of the scattering function, for most angles and for certain colors, have been done. However, the complete picture--how a specific color or a specific bandwidth of light propagates in water with a particular distribution of particles (living or dead), with specific amounts of various colored solutions--is not as well known.

Some way to model the biology must be determined. Whether particles are living or dead makes a difference which cannot be measured from a laboratory sample. Other effects, including horizontal stratification of biological and physical properties, may also require in situ information for accurate modeling. In some cases, bioluminescence will be important.

Absorption is indirectly important to scattering and is an important component of the total propagation model. The lack of direct absorption measurement of natural waters, especially coastal waters, leaves a gap in the complete data set for some of the best scattering determinations and tests that have been done in the past.

A list of relevant criteria follows:

A. Inherent Optical Qualities of Water

1. Absorption
2. Beam Attenuation
3. Volume Scattering Function
4. Scattering Coefficient
5. Albedo for Single Scattering
6. Index of Refraction
7. Spectral Characteristics, Wavelength, as it affects each of the above

B. Diffuse Attenuation, Irradiance at Depth

C. Particles

1. Amount and Size Distribution
2. Inhomogeneity, Layering
3. Temporal Changes, Daylight Effect
4. Mineral and Organic

D. Chemical Analysis, Solutions

1. Salinity
2. pH
3. Yellow Substance

E. Environment

1. Atmosphere
2. Bottom Reflectivity, Target Characteristics
3. Noise, Sunlight, Bioluminescence
4. Air-Water Interface, Waves
5. Currents and Tides
6. Temperature

II. CURRENT PROGRAMS IN OCEAN OPTICS

The work of other scientists and organizations was surveyed to determine their application to NORDA's planning. The following summary describes work considered important to MC&G. A detailed list of projects is included in Appendix A.

A. OFFICE OF NAVAL RESEARCH (ONR)

Most of the ONR program appears to support Strategic Laser Communications (SLC) development. If this high priority program is increased, the ONR support

for it is likely to increase. There are a number of basic research and exploratory development projects to better understand the variations in the downward vector irradiance (optical) coefficient and light propagation through natural waters. Many are applicable to airborne laser sounder technology. In turn, airborne laser sounders can provide the technology for testing some of the results of these projects.

ONR's basic research in bioluminescence is to better understand the seasonal distribution, abundance, and biology of luminous plankters and what causes them to display. ONR's exploratory development assesses the impact of bioluminescence on SLC. The program may provide useful information for night airborne laser sounder environmental modeling and S/N estimates.

The purpose of ONR's research program in optical filters is to develop a large-aperture, wide-angle field-of-view (FOV), narrowband, optical filter for selected blue-green center frequencies. Successful development or the discovery of a feasible approach would be of great value to airborne laser sounder receivers.

B. NAVAL OCEAN SYSTEMS CENTER (NOSC)

NOSC is supporting NRL in the development of an efficient blue-green laser for underwater applications. Their approach is to examine the feasibility of producing highly efficient blue-green coherent sources by the down-conversion of rare-gas halide laser output. An X-ray, pre-ionized, $HgBr_2$ dissociation laser was developed as a test bed for advanced pulsed power designs. A one-joule, X-ray, pre-ionized XeCl laser was downconverted with 40% energy efficiency in Pb vapor. The output of a 1.5 joule XeCl laser was successfully injection locked, and an E-beam pre-ionized $HgBr_2$ dissociation laser was developed with 0.8% efficiency with discharge enhancement greater than 100.

NOSC is supported by the Naval Material Command (NAVMAT) for several basic research programs in optical oceanography for proposed Navy surveillance and communications systems. The results should be valuable to NORDA. Likewise, NORDA's work in optical oceanography may be of interest to NAVMAT; if an application to surveillance or communication can be shown, NORDA could possibly look to NAVMAT for funding in this area.

C. DEFENSE ADVANCED RESEARCH PROJECTS AGENCY (DARPA)

DARPA supports SLC with projects to determine the feasibility of an optical solution for communications to submarines. The results of their program are of direct value to the MC&G program to develop airborne hydrographic surveying equipment. A NORDA program involving propagation modeling, as recommended in this study, should be of considerable value in SLC. DARPA also supports a feasibility experiment on airborne detection of ocean internal waves.

D. DEFENSE MAPPING AGENCY (DMA)

The DMA advanced development program, which includes the Hydrographic Airborne Laser Sounder (HALS) and the Active/Passive Scanner, is to reduce the cost and response time of coastal hydrographic charting by developing prototype survey systems and data reduction techniques. This part of the DMA effort is of such importance that reasonable projects will likely be fully supported. The development of a Coastal Ocean Optics Atlas for hydrographic survey planning is also being supported.

E. NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA)

NOAA had a program to develop an airborne laser sounder and has cooperated on the HALS program. They developed the Monte Carlo optical propagation model used by the HALS development. This model is not adequate to answer some important issues for future improvement in HALS, as identified by this study. Funding cutbacks have caused their sounder program to be dropped.

F. NAVAL OCEAN RESEARCH AND DEVELOPMENT ACTIVITY (NORDA)

NORDA has planned or supported basic research and advanced development projects in remote sensing oceanography, bathyphotometer development, satellite measurement of ocean optical properties, instrumentation issues in marine bioluminescence, and coastal ocean optics atlas, as well as this planning ocean optical study. All objectives support optical remote sensing to some degree. For example, the bioluminescence instruments may be useful to measure background noise for airborne laser sounder environmental modeling. NORDA should focus its diverse projects into a coherent ocean optics program. This study addresses only the MC&G implications of such a program.

Hydrographic surveying using optical remote sensors is the primary MC&G application of research in optical oceanography. Current approaches, such as the HALS system, rely on sounding water depths by timing the travel of short laser pulses from an aircraft to the surface and to the bottom, and back to the aircraft. To be of value to such systems, a model of how light propagates in water must include time. The only type of model which provides temporal pulse characteristics is the Monte Carlo simulation. The following investigators have all developed one or more Monte Carlo models of light propagation in natural waters:

1. Robert W. L. Thomas, EG&G/Washington Analytical Services Center, Inc.;
2. Clarence J. Funk, U. S. Naval Undersea Center;
3. Gilbert N. Plass & George W. Kattawar, Texas A&M University;
4. Howard R. Gordon, University of Miami;
5. Robert M. Lerner & John D. Summers, MIT Lincoln Laboratory;
6. L. R. Poole, D. D. Venable, & J. W. Campbell, NASA Langley Research Center.

None of these models has been tested with sufficient empirical data to verify their accuracy for hydrographic charting. This is due to the difficulty of obtaining optical sounding data in conjunction with ground truth measurements of the optical properties of the ambient water, especially the volume scattering function, a required input to the models. NORDA is now studying the hypothesis that the volume scattering function can be measured indirectly to sufficient accuracy for remote sensing, thus removing a significant barrier to the verification and improvement of optical propagation models.

G. NAVAL OCEANOGRAPHY COMMAND (CNOC)

CNOC supported a project to formulate concepts and options for the Navy's ocean prediction system of the year 2000 time period. These far future estimates

may point out promising approaches in optical oceanography that can be applied to MC&G.

III. MC&G REQUIREMENTS

Appendix B is a compilation of extracts from the Defense Mapping Agency "Guidance for Development of FY84-88 Navy Mapping, Charting and Geodesy (MC&G) Program." It establishes the Navy's need for basic and applied research in optical oceanography to support MC&G. It outlines deficiencies in existing coastal charts and the urgent need for Navy technology base support for advancing the development of optical remote sensors for hydrographic surveying. The Naval Oceanographic Office also has MC&G requirements.

The Hydrographic Airborne Laser Sounder (HALS) and the Active/Passive Airborne Bathymeter (paragraph 4.b.(2) of Appendix B) now being developed for hydrographic surveying will require extensive field testing under well-controlled conditions. They may also require precise optical data to calibrate them. Accurate system performance in the field will have to be clearly demonstrated before remotely sensed, optically determined depths will be incorporated into official Navy, DMA, or NOAA charts.

For these tests and demonstrations, an accurate optical propagation model will be required to correct for system errors caused by the environment and enable accurate comparisons to ground truth to be made. Accurate ground truth data must also be collected. Much remains to be done in the development and verification of useful propagation models. Existing mathematical approaches may be valid, but they need verification in the field. They may also need modification to fit nature or to conform to a particular remote sensor. It may be desirable to trade off some model accuracy to be able to use ground truth data that is easier to collect in the field. These questions need to be resolved and an accurate propagation model needs to be verified in the field.

The ground truth required in the future will depend, to some extent, on the optical propagation model used and the collection equipment available. More efficient ground truth instruments may have to be developed. Airborne system testing will require extensive area coverage in a very short time. Current techniques and available instruments cannot provide this coverage. The development of new equipment to better support the desired propagation model is required. This development should also consider the needs of scientists in other branches of oceanography. For instance, in 1977 the ocean optics workshop held at the Scripps Institution of Oceanography concluded that ". . . suitable instruments are not yet available for the direct measurement of the sea water absorption coefficient 'a', and the volume scattering function $\beta(\theta)$ for θ near 0° and 180°. Such instruments are badly needed for both basic oceanographic studies and system model verification." Basic research is required to determine which measurements are most needed, and exploratory development is required to find the most feasible approach to practical field instrumentation.

Bioluminescence of marine organisms may affect an optical remote sensor, especially at night.

Efficient planning for hydrographic surveys will require prior knowledge of the optical characteristics in the area to be surveyed. Water clarity, seasonal variation, biologic data, bottom reflectivity, and other environmental characteristic data will be required. The establishment of a world data bank for such information should be considered.

The small, usable aperture of narrowband interference filters severely limits the use of airborne sounders in daylight. Development of a narrow band (0.1 nm or less) optical filter capable of accepting light at angles of 30 mrad or more is required. Such a filter would be especially useful for hybrid systems that can operate only in daylight.

IV. NORDA RESOURCES

A. PERSONNEL

NORDA personnel have many years of experience in optical airborne remote sensing and the ground truthing required for support. Code 372 personnel have experience from the CAPS, AOL, and HALS programs, and Code 335 personnel have long been involved with ground truthing for airborne or satellite remote sensors. Both codes have mutual interests and activities in coastal ocean optics, and efforts are underway to resolve overlap areas to provide more effective use of resources.

Other NORDA experience includes underwater equipment design and fabrication (Code 352), laser backscattering in sea water (Code 343), optical detection of internal waves (Code 541), and bioluminescence measurement (Code 542).

B. EQUIPMENT

During the CAPS and HALS programs, some support equipment was purchased and remains available to Code 372. These include:

1. Frequency-doubled NdiYAG laser, ILS Model NT-274
2. Two Transmissometers
3. Hunterlab Reflectometer, Model D-40

Code 335 has a state-of-the-art irradiance meter and an N_2 pumped dye laser.

Code 542 has supported the development of a closed bathyphotometer and is currently developing an open bathyphotometer. Calibration systems are being planned.

V. RECOMMENDED PROGRAM

A. NORDA

An integrated optical oceanography program covering basic research, exploratory development, and advanced development is recommended, using, in addition to the resources of Code 372, all the applicable resources of NORDA. In particular, the following NORDA groups in addition to Code 372 have capabilities and resources which may be required to provide an optimum program in support of MC&G.

1. Code 331, Physical Oceanography Branch
2. Code 334, Biological/Chemical Oceanography Branch
3. Code 335, Remote Sensing Branch
4. Code 343, Acoustics Branch
5. Code 352, Instrumentation Branch
6. Code 371, Pattern Analysis Branch

NORDA Codes 541, 542, and 550, and ONR Detachment 425AC should be considered potential sources for requirements and funding. Defense Mapping Agency advanced development programs are managed by the NORDA codes, and many basic research and exploratory development programs in optical oceanography are funded by ONR.

This study does not address the question of a comprehensive ocean optics program, although there is a clear need for this within NORDA, but discusses specific topics that Code 372 can pursue for MC&G applications. Such projects are considered next.

B. BASIC RESEARCH

A project to provide a better understanding of laser propagation in the shallow-water environment is recommended. This improved understanding is expected to provide a payoff in pointing the way toward improved technology for obtaining water depth measurements in coastal regions from various laser sensors. The project would address the development of spectral propagation models and environmental optical noises. The goal would be to provide means of improving the signal-to-noise ratio for new laser sensors and processors to accomplish more accurate results in deeper margins and more turbid regions of shallow water.

The primary impact of this research on the Navy would be to improve the environmental models used for predicting the performance of the laser systems used for hydrographic surveying. A better understanding of these models would improve the performance of the laser sensors and enable better systems to be developed. Specific MC&G areas applicable to this effort are: (1) airborne laser survey system improvements contributing to increased speed of operation, depth penetration, and accuracy; (2) better modeling of worldwide coastal ocean optical processing in support of electro-optical bathymetric techniques; and (3) improvement of airborne multispectral bathymetry accuracy and data processing. Results of the proposed research will contribute in each of these areas. Areas outside the scope of MC&G, such as SLC, might also benefit from this research.

Aspects of this research would be similar to the ONR project (RR0310301) and some NORDA Code 335 programs to develop and test a model that predicts diffuse attenuation in clear ocean waters free of coastal influences. However, this project is concerned specifically with coastal waters and will attempt to predict the detailed structure of the return waveform envelope of laser sensors used over coastal waters.

The design and execution of experiments in the field would be a cooperative effort, with NORDA Code 335 personnel providing assistance in the area of optical water measurements. Code 372 would concentrate on laser propagation modeling and potential applications to improvements of laser hydrographic systems and system development experimental requirements.

The basic research recommended above can be expected to provide a payoff in pointing the way toward improved system concepts for obtaining water depth in coastal regions using techniques such as the Hydrographic Airborne Laser Sounder (HALS), the multispectral Active/Passive Scanner system, or water penetration photogrammetry.

C. EXPLORATORY DEVELOPMENT

Not all the basic measurement equipment and technology has been developed to conduct appropriate experiments for the above study. The development of a total ocean optical measuring system capable of testing optical propagation models is recommended. System characteristics should allow for the experimental testing of propagation models relevant to the problem of special oceanic backscattering of airborne laser light. Results of such work provide a better understanding of other passive airborne light problems such as multispectral scanners and strategic communication lasers.

The optical propagation models to be evaluated by this system would be provided by the basic research program and would be used to support the advanced development programs of airborne sounders required for hydrographic surveying. To determine which propagation model is the most effective for field testing optical remote sensors, the tradeoffs between the most desirable model inputs and the measurements that can be most effectively made in the field need to be studied. Some of the most desirable inputs, such as complete volume scattering functions at various spectral frequencies, are impossible to obtain quickly and accurately in the field. Another desirable input, absorption, has seldom been measured in the field. The most effective tradeoff between the ideal and the more easily obtained information is not known. A part of an exploratory development study should be to evaluate the relative merits and sensitivities of various model inputs. The effect on the model of degraded accuracy and incomplete observation would be a part of this study. A recognized authority in optical oceanography would be required to conduct such a study.

Development of a narrowband, wide field-of-view optical filter was started a few years ago to support the SLC program. Such a filter would be of great value to optical remote sensors, and a study to determine which approach would be the most fruitful is recommended. SLC requirements are quite different from those for hydrographic sounders in both spectral and field-of-view characteristics. Development approaches considered unfeasible for SLC could possibly be useful to hydrographic sounders. The sounders do not need as wide a field-of-view, and they operate over waters that have different spectral characteristics. A feasible green optical filter design may be available as a by-product of SLC research.

D. ADVANCED DEVELOPMENT

Successful model development under the suggested basic research program may produce knowledge which can be used to modify existing airborne laser sounders to significantly improve their performance, or which can be used to design better new systems. The new knowledge may also lead to improvements or new designs for other types of remote sensors. At least three new advanced development programs are envisioned:

1. HALS Modification

Field test results of an improved optical propagation model will demonstrate how the HALS can be improved. Proposals for specific advanced development modifications of the HALS can then be made to the DMA. Possible design changes include installation of a temperature-controlled optical filter in the receiver, changes in laser beam spread or receiver field-of-view limitations, and a change in the size of the receiver aperture. An improved model will also improve the accuracy of the HALS data reduction.

2. Reconnaissance System Development

Results obtained using the improved model will show how systems could be designed to locate mines optically or to rapidly produce hydrographic charts of reconnaissance quality. Other applications of possible interest to OP-952, NAVAIR, or MCDEC may also be found. A final advanced development model might have to be contracted for by one of the Navy development laboratories such as NADC, but development of a design concept and technical specifications will require the know-how in optical oceanography developed at NORDA by this program.

3. Improved Multispectral Scanner

An improved optical propagation model will provide information which could improve the interpretation of multispectral data collected in shallow water coastal areas. Specific spectral information on bottom reflectivities and transmission through the water may point out significant potential design improvements for future multispectral remote sensors. Improved sensors of this type will also be able to provide information about bottom characteristics such as texture, color, or composition.

E. RECOMMENDED FUNDING ESTIMATE

	NORDA Code	Duration In Years	Estimated Total Funding
Basic Research			
1. Coastal Waters Optical Models for Laser Propagation	372	5	$ 700,000
2. Optical Absorption and Scattering in Natural Waters	372	2	200,000
3. Bioluminescence Modeling	372	2	150,000
4. Correlation of In Situ and Satellite Optical Data	335	1	25,000
5. Satellite Calculation of Bathymetry	335	2	370,000
6. Alternate Applications of the HALS System	335	3	465,000
Subtotal			$1,910,000
Exploratory Development			
1. Ocean Optical Propagation Measurement System Technology	372	5	765,000
2. Blue-Green Filter Study	372	2	135,000
3. Laser Study	372	1	45,000
4. Modification of Optical Propagation Model	372	1	40,000
5. Hydrographic Applications	335	2	100,000
Subtotal			$1,085,000
Advanced Development			
1. Bottom Reflectometer	372	1	80,000
2. Spectral Absorption Meter	372	2	110,000
3. Quantitative Measurements of Water Clarity and Sediment Concentration from MSS	335	2	198,000
4. Coastal Atlases	335	3	205,000
5. Algorithm Development for Multisensor Bathymetry	335	3	250,000
6. HALS Support	335	3	50,000
7. MS Sound Atlas	335	1	20,000
8. LANDSAT Classification Techniques	335	1	20,000
Subtotal			$ 933,000
TOTAL			$3,928,000

APPENDIX A

PROJECTS IN OPTICAL OCEANOGRAPHY

SPONSOR: ONR

PERFORMER: NOSC

TITLE: Non-Classical Optical Background Noise

APPROACH: Measure irradiance and temporal fluctuations of the optical background irradiance for a variety of meteorological conditions and water types.

REMARKS: Improvement of laser depth sounder environmental model.

SPONSOR: ONR (425 AC)

PERFORMER: Tetra Tech, Inc.

ACCESSION: DN 975125

DATE: 19 Feb 82

TITLE: Light Scattering in the Sea

OBJECTIVE: Derive a theory for scattering through large angles and for pulsed laser propagation in realistic ocean/atmospheric environments.

APPROACH: Continue generalization of the history of multiply scattered light and its computational techniques.

REFERENCE: Wells, Harris & Lin, "Multiple Scatter of Collimated Irradiance," Journal of Optical Society of America, March 1981.

SPONSOR: ONR

PERFORMER: U. of Paris

DATE: 16 Dec 81

PROGRAM: 6.1

TITLE: MOBIX (Marine Optical and Biological Experiment)

OBJECTIVE: Study optical properties of the ocean and their relationships with biological processes and transport of suspended matter. Study propagation and dissipation of solar energy. Intercalibrate instruments internationally.

APPROACH: Extensive measurements will be made in three areas: Clear waters west of Madeira; upwelling off Morrocco; and turbid waters near Dakar.

REMARKS: Supports SLC

SPONSOR: ONR (486)

PERFORMER: Oregon State U.

ACCESSION: DN175334

DATE: 4 June 81

PROGRAM: 61153N, RR0310301

TITLE: Navy Environment: Environmental Effects on Optical Propagation

OBJECTIVE: Develop and test a one-dimensional model which predicts the downward irradiance coefficient from biological, physical and incoming solar radiation measurements.

APPROACH: Multi-year, multi-institution experimental effort in an ocean free of coastal influences.

REMARKS: Supports SLC

SPONSOR: ONR (486)

PERFORMER: Oregon State U.

ACCESSION: DN575025

DATE: 8 Dec 81

PROGRAM: 61153N, RR0310301

TITLE: Navy Environment: Optical Properties of Sea Water

OBJECTIVE: Determine the optical properties of sea water, their variability, and resultant effects on artificial and natural underwater light.

APPROACH: Develop lab. settling tube, perform measurements of the attenuation of pure water, develop relationship of scattering to particles, and participate in a high energy benthic boundary layer experiment.

SPONSOR: ONR

PERFORMER: NRL (6530)

ACCESSION: DN780276

DATE: 1 Oct 81 (Completed)

PROGRAM: 61153N, RR0110742

TITLE: Particulate Scattering

OBJECTIVE: Study multiple scattering effects of particulate scattering media on optical signals.

APPROACH: Monodisperse latex spheres will be used in lab experiments with HeNe and Argon-ion lasers.

SPONSOR: ONR (425AC)

PERFORMER: Texas A&M

ACCESSION: DN875169

DATE: 22 Feb 82

PROGRAM: 61153N, RR0310301

TITLE: Navy Environment: Underwater Light Polarization Measurements

OBJECTIVE: Build and test an instrument to measure the polarization of scattered light and which is suitable for use on a ship.

APPROACH: Modify a lab instrument which measures polarization and test it in the field.

SPONSOR: ONR (486)

PERFORMER: U. of South Florida

ACCESSION: DN223364

DATE: 5 Aug 81

PROGRAM: 61153N, RR0310301

TITLE: Navy Environment: In Situ Optical Measurements of Particle-Sea Interaction

OBJECTIVE: Develop an in situ holographic camera to measure particle size distribution and settling speeds.

APPROACH: In-house fabrication

SPONSOR: NMC (NDLP)

PERFORMER: NOSC

ACCESSION: DN187526

DATE: 1 Oct 82

PROGRAM: 61152N, ZR00001

TITLE: Sea Radiance Spectroscopy

FUNDING: FY83--$50,000

OBJECTIVE: Obtain high-accuracy, high-resolution spectroscopic data of upwelling irradiance from natural ocean waters.

APPROACH: Design, fabricate and field a portable tele-spectral-photometer with slow-scanning, narrowband filters and off-shelf optical detectors. Use from NOSC tower near Mission Bay.

REMARKS: Environmental noise background data for S/N estimates for airborne laser sounders.

SPONSOR: ARPA

PERFORMER: OSC

ACCESSION: P811P65

DATE: Oct 81

TITLE: Physics of the Ocean Optical Radar

OBJECTIVE: Demonstrate that structure in the ocean can be detected and mapped with a subsurface laser radar. Demonstrate that this structure can be related to physical phenomena occurring within the ocean.

APPROACH: Construct a blue-green LIDAR and operate from a surface craft under controlled conditions.

REMARKS: Technology is applicable to airborne laser sounding.

SPONSOR: NASA

PERFORMER: NASA

ACCESSION: VN170341

DATE: 9 May 80

TITLE: Coastal and Estuarine Dynamic Processes Research

OBJECTIVE: Provide a scientific basis for the interpretation and use of remote sensing in studies of an estuarine and coastal marine environment. Includes study of optical properties of turbid waters.

SPONSOR: ONR (483)

PERFORMER: U. of Delaware

ACCESSION: DN575127

DATE: 28 June 82 (Terminated)

PROGRAM: 61153N, RR0310301

TITLE: Sediment Dynamics: Sources and Transport Mechanisms of Sediments in the Oceans

SPONSOR: NADC

PERFORMER: NRL

ACCESSION: DN980464

DATE: 1 Oct 80

PROGRAM: 62711N, WF11100000

TITLE: Optical Scattering Layer-Hydrodynamics

OBJECTIVE: Classified

APPROACH: Classified

SPONSOR: NELX

PERFORMER: NOSC

ACCESSION: DN988540

DATE: 1 Oct 80

PROGRAM: 62711N, ZF11123100

TITLE: Ocean Color Investigation

FUNDING: FY83 $385,000 planned
FY84 $415,400 planned

OBJECTIVE: Evaluate the potential of detecting submarines from airborne and satellite platforms by observing induced color changes in the ocean surface water.

APPROACH: Classified

SPONSOR: DARPA

PERFORMER: NOSC

ACCESSION: DN687623

DATE: 1 Oct 82

PROGRAM: 62301E

TITLE: Submarine Laser Optical Communications Program

FUNDING: FY83 $1,761,000
FY84 $2,706,000

OBJECTIVE: Determine practicality and suitability of optical solution for communications to submerged submarines.

APPROACH: Provide system engineering, technical advice, and coordination to program sponsors (NAVELEX, ONR & DARPA)

REMARKS: Technology is applicable to laser remote sensing.

SPONSOR: ONR

PERFORMER: NADC, Warminster, PA 18974

PROGRAM: 62721N, RF21222801

TITLE: SLC Support

OBJECTIVE: Obtain data to determine the propagation statistics of a laser beam in water and establish the relationship between the pulse stretching and attenuation produced when a laser beam propagates through a cloud and that associated with the back reflected portion of the beam.

APPROACH: Classified

SPONSOR: ONR (240)

PERFORMER: Stanford Research Inst. Int'l.

ACCESSION: DN275083

DATE: 5 Feb 82

PROGRAM: 62721N, RF21222801

TITLE: Surveillance: Ocean Optics Support

FUNDING: FY83 $601,000

OBJECTIVE: Establish that ocean thermal structure can be measured by airborne LIDAR.

APPROACH: Consult, build and operate data acquisition and analysis system; purchase and operate data collection system for sea truth; and design, construct and test ocean optical instruments.

REMARKS: New instruments for airborne sounder ground truth measurements.

SPONSOR: NOSC

PERFORMER: NRL (6540)

ACCESSION: DN680033

DATE: 15 Feb 82

PROGRAM: 62762N, F62583

TITLE: Blue-Green Laser Technology

FUNDING: FY83 $250,000

OBJECTIVE: Develop efficient blue-green laser.

APPROACH: Examine the feasibility of down conversion of rare-gas halide lasers. Investigate discharge-pumped Hg Br_2 dissociation lasers.

REMARKS: Transmitter source for future airborne laser sounders.

SPONSOR: DMA

PERFORMER: NORDA

ACCESSION: DN794437

DATE: 1 Oct 81

PROGRAM: 63701B, 3201

TITLE: HALS

OBJECTIVE: Develop an operational airborne sounder

APPROACH: Procure an Advanced Development Model from industry.

SPONSOR: DMA

PERFORMER: NADC

ACCESSION: DN981016

DATE: 15 Feb 81

PROGRAM: 63701B, MPR0327

TITLE: Laser Bottom Mapper Component Development and Support

OBJECTIVE: Provide technical support and component development for HALS.

APPROACH: Investigate PMTs, CTD digitizers, high density magnetic recording, solid state and metal vapor lasers and new high speed digitizers.

REMARKS: Improvements of HALS.

SPONSOR: NORDA

PERFORMER: AVCO Everett Research Lab.

ACCESSION: DN194406

DATE: 19 Oct 81

PROGRAM: 63701B, 3201

TITLE: HALS Contract for ADM

OBJECTIVE: Develop an operational airborne sounder

APPROACH: Design and fabricate a complete system under a CPFF contract.

REMARKS: System will be used by NAVOCEANO for hydrographic surveying.

REFERENCE: DN794437 (HALS)

SPONSOR: DMA

PERFORMER: NCSC

PROGRAM: 63701B, 3201

FUNDING: FY83 $375,000 planned
FY84 $600,000 planned

TITLE: Active/Passive Airborne Bathymetry

OBJECTIVE: Develop an Airborne Multispectral Sounder, controlled by a laser sounder, for rapid hydrographic surveying.

SPONSOR: NADC

PERFORMER: Scripps Institution of Oceanography

ACCESSION: DN081270

DATE: 15 Feb 81

PROGRAM: 63701B, MPR9327

TITLE: Optical Oceanographic Support for Laser Bathymetry System Development

OBJECTIVE: Provide analytic and engineering services in optical oceanography for development of airborne laser bathymetry systems.

APPROACH: Determine feasibility of using NIMBUS data to get K measurements in HALS survey areas.

REMARKS: Environmental data for HALS survey planning.

REFERENCE: DN981016

SPONSOR: ONR (221)

PERFORMER: Scripps Institution of Oceanography

ACCESSION: DN875470

DATE: 5 Oct 81

PROGRAM: DARPA 3650, 62721N, RF21222801

TITLE: Ocean Optical Properties

OBJECTIVE: Gather ground truth for NIMBUS 6 diffuse attenuation coefficient measurement program.

APPROACH: Use ship of opportunity.

REMARKS: Atlas of K values would be useful to plan laser sounder missions.

REFERENCE: R. W. Austin, "Remote Sensing of the Diffuse Attenuation Coefficient of Ocean Water," AGARD-CP-300, Sept. 1981.

SPONSOR: ONR

PERFORMER: NRL (6540)

ACCESSION: DN091232

DATE: 1 Oct 81 (Completed)

PROGRAM: 62301E

TITLE: Blue-Green Filters

OBJECTIVE: Ascertain suitability of Cs atomic resonance filter for use with XeCl laser.

APPROACH: Measure efficiency and other characteristics at 459 nm resonance.

REMARKS: Improved filter for airborne laser sounders.

SPONSOR: ONR (471)

PERFORMER: Hughes Research Lab., Malibu, CA

ACCESSION: DN075834

DATE: 18 Nov 81

PROGRAM: 61153N, RR0220601

TITLE: Blue-Green Filter Materials

OBJECTIVE: Investigate materials that will lead to a zero crossing in birefringence and to prediction of filter characteristics.

APPROACH: Investigate complex sulfide and oxide-sulfide materials. Calculate filter characteristics of known and predict those of new materials.

REMARKS: Improved filter for airborne laser sounders.

SPONSOR: ONR (240)

PERFORMER: Rockwell Int. Science Center

DATE: 25 Nov 80

PROGRAM: 62721N, RF21222801

TITLE: Anomalous Dispersion Filter

APPROACH: Compute peak and passband widths for ideal LYOT filters. Identify alternative materials.

REMARKS: Improvement of airborne laser sounder daylight filter.

SPONSOR: ONR (220)

PERFORMER: Lockheed Missile & Space Co.

ACCESSION: DN875727

DATE: 23 June 81 (Completed)

PROGRAM: 62301E, RF21222801

TITLE: LYOT Filter Technology

OBJECTIVE: Develop narrowband, wide field-of-view, large aperture optical filter.

APPROACH: Feasibility of a birefringent LYOT filter will be investigated.

REMARKS: Improvement of airborne laser sounder receiver filter.

SPONSOR: ONR (420D)

PERFORMER: Scripps Institution of Oceanography

ACCESSION: DN075315

DATE: 7 Jan 82

PROGRAM: 61153N, RR0310301

TITLE: Mechanisms of Marine Bioluminescence

OBJECTIVE: Develop methods to detect and characterize bioluminescence.

APPROACH: Develop and deploy spectral, kinetic and biochemical monitoring systems.

REMARKS: Improvement of airborne laser sounder environmental models.

SPONSOR: ONR

PERFORMER: U.C., Santa Barbara

DATE: 22 May 81

PROGRAM: 61153N, RR0310201

OBJECTIVE: Bioluminescence research

REMARKS: Improve nighttime S/N of airborne laser sounders.

SPONSOR: ONR

PERFORMER: NRL (4351)

ACCESSION: DN480019

DATE: 15 Feb 82

PROGRAM: 61153N, RR0412641

TITLE: Bioluminescence

FUNDING: FY83 $156,000

OBJECTIVE: Better understand the seasonal distribution, abundance and biology of luminous planktors and their relation to the detection of luminously haloed objects of naval interest.

APPROACH: Perform literature searches, field surveys, and lab experiments.

REMARKS: Background noise data for airborne laser sounder signal equation.

SPONSOR: ONR (240)

PERFORMER: Scripps Institution of Oceanography

ACCESSION: DN075704

DATE: 16 Jun 81

PROGRAM: 62721N, RF21222801

TITLE: Marine Bioluminescence Studies

OBJECTIVE: Characterize marine bioluminescence emissions to determine impact on SLC.

APPROACH: Prepare equipment and make long-term measurements in Scripps Canyon.

REMARKS: Airborne laser sounder S/N model information.

SPONSOR: ONR

PERFORMER: NOSC, San Diego

TITLE: Extended Bioluminescence Cruise

OBJECTIVE: Locate, measure, record and characterize perturbations in the underwater optical background produced by irradiance scintillation, waves, clouds, biologic organisms, and bioluminescence.

APPROACH: Acquire data from submarine USS DOLPHIN.

REMARKS: Improve knowledge of optional background noise in airborne laser sounder environment. Supports SLC.

SPONSOR: NADC (AIR 370E)

PERFORMER: NRL

ACCESSION: D880400

DATE: 1 Oct 80

PROGRAM: 62711N, WF11125000

TITLE: Bioluminescence Applications

FUNDING: $190,000 planned

OBJECTIVE: Classified

SPONSOR: NORDA

PERFORMER: NOSC

DATE: 1 Oct 81

PROGRAM: 6.1

TITLE: Bathyphotometer Development

OBJECTIVE: Design and develop a bathyphotometer for NAVOCEANO for bioluminescence survey work.

APPROACH: A detector is designed to pull seawater through a viewing chamber observed by 4 PMTs, each with a different optical filter. Digital data is recorded topside.

REMARKS: The instrument can support collection of data for input to airborne laser sounder environmental model.

SPONSOR: NORDA

PERFORMER: Planning Systems, Inc.

ACCESSION: DN094484

DATE: 21 May 82

PROGRAM: 63704N, R0118OS

TITLE: Instrumentation Issues in Marine Bioluminescence and Physical Oceanography

OBJECTIVE: Document current state of the art of both physical and bioluminescent instrumentation. Prepare 5-Year Plan for future instrument development.

APPROACH: Collect and assemble data, describe characteristics and publish report. Assess future needs.

REMARKS: Noise data for airborne laser sounders.

SPONSOR: DMA

PERFORMER: NORDA

ACCESSION: DN294410

DATE: 1 Oct 81

PROGRAM: 63701B, 3202

TITLE: Water Penetration Photogrammetry

OBJECTIVE: Improve shallow sea charting capability using photogrammetric and densitrometric techniques.

APPROACH: Evaluate data from Bahamas Photobathymetric calibration range.

SPONSOR: CNOC

PERFORMER: NORDA

ACCESSION: DN294-418

DATE: 1 Oct 81

PROGRAM: 35112N

TITLE: Impact of Evolving Technology on Future Ocean Prediction Systems Capabilities

OBJECTIVE: To formulate concepts and options for the Navy's ocean prediction system of the Year 2000 time period.

APPROACH: Assess current research and technology and trends in ocean prediction.

REMARKS: Improvement of environmental modeling for airborne remote sensors.

APPENDIX B

EXTRACTS FROM THE DEFENSE MAPPING AGENCY "GUIDANCE FOR DEVELOPMENT OF FY84-88 NAVY MAPPING, CHARTING AND GEODESY (MC&G) PROGRAM"

"1. (U) General. The MC&G dedicated resources of the Navy, which include survey ships and aircraft along with the MC&G assets of the Naval Oceanographic Office are vital to the support of DoD programs. Thus, the Navy program must ensure that the rate of collection, reduction, and delivery of hydrographic, bathymetric, and geophysical data reflect the total collection requirement necessary to support the nautical portion of the DoD MC&G program. Guidance that follows is intended to assure the continued operational effectiveness of U.S. and Allied Forces through the provision of MC&G products and services in support of strategic and tactical forces . . .

"3. (U) Specific Guidance . . .

"a. (U) Hydrographic Surveys and Data Reduction: . . .

"(4) (U) Approximately 63% of the coastal charts and 60% of DMA Harbor and Approach Charts have been evaluated 'Limited Use.' While conservative seamanship and the following of established routes have minimized the number of groundings that can be attributed to Limited Use charts, these are options which will not always be enjoyed in a period of national emergency. Considering rates of change in these types of charts, due both to man-made and natural forces, it is unlikely that any decrease in the percentage of Limited Use charts can be accomplished with present resources. Therefore, the following are program considerations:

"(a) (U) Maintain a dedicated coastal survey capability available for operations worldwide.

"(b) (U) Increase the productivity of the coastal survey program as a matter of primary importance. Continuing efforts should be made to increase data acquisition capabilities, whether by automated or manual methods . . .

"4. (U) Research and Development (R&D).

"a. (U) DMA maintains a long-range, comprehensive Category 6.3/6.4 R&D program plan to develop tools and techniques for the production of reliable charts and related nautical products. The driving priorities for this program, with respect to both the data collection and processing, are: the initial detection of hazards to navigation; the planimetric revision of chart features; and the complete description of all features, including water depth.

"b. (U) This program is divided into three acquisition categories: space sensors, airborne sensors, and shipborne sensors.

"(1) (U) Use of data from sensors with a capability for providing metric hydrographic information has been studied by DMA for a number of years. Initially, water depth information and planimetry were extracted stereometrically from panchromatic photography. Later, it was discovered that a multispectral

multispectral scanner would permit greater water penetration in blue-green bands and would assist in water depth analysis by comparing information from different spectral bands. Recently, it has also been theorized that the relationship between various ocean surface phenomena and bathymetry can be usefully quantified. All of these aspects are being pursued, including feature extraction and positioning, depth determination, and improved automatic data base management.

"(2) (U) Airborne sensors presently under development include the Hydrographic Airborne Laser Sounder (HALS) and an active/passive airborne bathymeter. In addition, various high pulse rate lasers are being considered for use in a future system. The HALS employs a pulsed, scanning blue-green laser that measures the time difference between the surface and bottom return to calculate depth. It is programmed to be in use in the helicopters carried by the two Navy coastal survey ships by 1984. The active/passive system measures light attenuation in different spectral bands to determine water depths, periodically calibrating these measurements with a low pulse rate laser. This system is planned for employment in a fixed wing aircraft about 1986, or as soon as GPS is operational. Advanced automatic data processing is necessarily a major aspect of airborne survey developments . . .

"(4) (U) To support the development of depth extraction algorithms for remote multispectral scanners, as well as to evaluate the hydrographic potential of other satellite, airborne and shipborne sensors, DMA has developed by means of an intensive ground truth and remote imaging program, a photobathymetric calibration area on the Bahama Banks.

"(5) (U) Increased emphasis will be placed in the future on automating the stereo photogrammetric process for shallow water bathymetry, and in automating the use of all data for charts and other nautical products, including special digital products. For this purpose, advances made for other DMA programs in the area of artificial intelligence/automated feature extraction will be applied to hydrography.

"c. (U) DMA urgently requires Navy technology base (Category 6.1/6.2) and Category 6.3 support for advancing the foregoing developments and future efforts. Hence, it is essential that Navy resources be programmed in the following areas (listed in order of priority):

"(1) (U) Techniques for obtaining accurate bathymetry from space sensors.

"(2) (U) Methods for automatic processing of hydrographic data from all types of sensors; including artificial intelligence, automated feature extraction and image processing, and related advances in data base management.

"(3) (U) Advanced survey sonar technology; especially a highspeed, long range, high resolution depth quantifying sidescan system.

"(4) (U) Remote sensing of coastal tides.

(5) (U) Airborne laser survey system improvements contributing to increased speed of operation, depth penetration, and accuracy.

"(6) (U) Better modeling of worldwide coastal ocean optical processes in support of electro-optical bathymetric techniques.

"(7) (U) Improvements in airborne multispectral bathymetry accuracy and data processing; scanner, laser and computer technology as well as related coastal optical oceanography.

"(8) (U) Better understanding of ocean dynamic processes whose remotely detectable surface manifestations relate to bathymetry; e.g., surface topography, wave train perturbations and thermal variability.

"(9) (U) Better understanding of geomagnetics and gravity as they relate to sea floor topography.

"(10) (U) Advanced horizontal positioning systems for air and surface survey platforms.

"d. (U) Substantial improvement in hydrographic survey and data processing capability has been a recognized need for a long time, from the standpoints of speed, accuracy, and cost effectiveness. The data deficiency is so large, and the cost of surveys so high, that we must be able to quickly and cheaply collect very large quantities of data of sufficient accuracy to support safe navigation. A well directed RDT&E program is the most promising solution to this need. The best program possible will be one conducted jointly and closely coordinated by both Navy and DMA; Navy with technology base (6.1/6.2) and 6.3 and DMA with its 6.3/6.4 category work, such that knowledge and techniques flow logically and efficiently from fundamental physical knowledge to system operations. The recently implemented Memorandum of Understanding between DMA and Navy establishing the Naval Ocean R&D Activity (NORDA) as the single lead Navy MC&G laboratory, and a strong focal point for the entire program, should be an effective means of accomplishing this."

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This plan presents an ocean optics program to support the MC&G objectives of the Navy. A summary of the optical oceanographic research being performed by others is provided, requirements and resources are reviewed, and an integrated R&D program is recommended.

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